

1. EXECUTIVE SUMMARY

For this analysis, we consider cmd.par files from the Combustion Integrated Rack (CIR) facility on GMT 2022-04-14 and GMT 2022-06-28. We assert that the two CIR commands **RECIRCULATION FANS SET SPEED (0xC209)** and **MODULES PUMP SET SPEED (0xC208)** are expected to give a specific equipment start time that can be used to verify those times correlate well with timing from Space Acceleration Measurement System (SAMS) vibratory measurements. SAMS timing is [almost always] synchronized via Network Time Protocol (NTP) with a server on the International Space Station (ISS).

All of the SAMS data plots presented in this document were computed from measurements made by the Triaxial Sensor Head - Ethernet Standalone (TSH-ES, S/N 05, aka "es05") sensor mounted in the CIR facility (LAB1S3) on the ISS.

The SAMS measurements from GMT 2022-04-14 & 2022-06-28 have been analyzed, and the acceleration data from those days show good SAMS timing correlation relative to the CIR cmd.par setting change timestamps, namely for CIR pump & fans' start and stop times.

More details in the sections below show relatively strong spectral peaks that start or stop with CIR commands to change equipment settings.

2. QUALIFY

The details in Table 2 on 20 show information from CIR command settings along with notes and hyperlinks to SAMS plots from two operations periods:

(1) GMT 2022-04-14

- 1) GMT 2022-04-14/17:20 – CIR pump and fans **start**
- 2) GMT 2022-04-14/17:50 – CIR pump and fans **stop**
- 3) GMT 2022-04-14/18:45 – CIR pump and fans **start** (again)
- 4) GMT 2022-04-14/21:30 – CIR pump and fans **stop** (again)

(2) GMT 2022-06-28

- 1) GMT 2022-06-28/14:15 – CIR pump and fans **start**
- 2) GMT 2022-06-28/18:00 – CIR pump and fans **stop**
- 3) GMT 2022-06-28/20:50 – CIR pump and fans **start** (again)
- 4) GMT 2022-06-29/00:40 – CIR pump and fans **stop** (again)

Before we dive into quantifying the impact of CIR equipment operations, we qualify the vibratory signals attributed to these CIR equipment using a series of color spectrograms computed from the SAMS measurements.

GMT 2022-04-14/17:00, 5-Hour Overview Spectrogram

The spectrogram of Figure 1 on page 4 shows both on/off periods from GMT 2022-04-14. The spectral signature of the CIR fans are evident at just above 50 Hz or so. We see 2 strong, narrowband spectral peaks as red, horizontal streaks marked by the blue time hacks on the horizontal axis. Likewise for the pump, albeit a notably weaker disturbance, its signature shows up just above 30 Hz or so and it is unclear why we see 2 spectral peaks. The frequency band used to quantify the pump & fans' are shown on the vertical, frequency axis.

GMT 2022-06-28/13:30, 5-Hour Overview Spectrogram

The spectrogram of Figure 2 on page 5 shows the first on/off period from GMT 2022-06-28. The spectral signature of the CIR fans are again evident, but now closer to 60 Hz. We again see 2 strong, narrowband spectral peaks as red, horizontal streaks marked by the blue time hacks on the horizontal axis. We also see a step down in frequency before the end of this first operational period. For the pump, we again see a notably weaker disturbance, its signature shows up just above 30 Hz or so. The frequency band used to quantify the pump & fans' are shown on the vertical, frequency axis...nearly the same for the pump, but a bit higher for the fans.

GMT 2022-06-28/20:00, 5-Hour Overview Spectrogram

The spectrogram of Figure 3 on page 6 shows the second on/off period from GMT 2022-06-28. The spectral signature of the CIR fans are again evident, but now closer to 60 Hz. We again see 2 strong, narrowband spectral peaks as red, horizontal streaks marked by the blue time hacks on the horizontal axis. We again see a step down in frequency before the end of this second operational period. For the pump, we again see a notably weaker disturbance, its signature shows up just above 30 Hz or so. The frequency band used to quantify the pump & fans' are shown on the vertical, frequency axis...nearly the same for the pump, and a bit lower for the fans compared to earlier in the day.

A Series of Zoomed-In Spectrograms to Better Show Timing

The series of spectrograms from Figure 4 on 7 through Figure 12 on 15 show zoom-ins for a better look at spectral peak start and stop times, better than the previous overview spectrograms.

3. QUANTIFY

Full quantification details for each of the pump and fans' operations and operational periods are shown in Table 1 on page 19.

As a means of quantifying the impact of CIR's fans and pump, we consider per-axis power spectral density (PSD) plots computed from SAMS acceleration measurements and employ Parseval's theorem to arrive at interval root-mean-square (RMS) acceleration versus time plots...this, in an attempt to identify and *mostly* isolate just the impact of the CIR facility pump and fans. The next 3 subsections in this Quantify section are identical to the respective subsections in the previous Qualify section.

GMT 2022-04-14/17:00, 5-Hour Interval RMS vs. Time

The interval RMS vs. time plot of Figure 13 on page 16 shows both on/off periods from GMT 2022-04-14, 5-hours starting at 17:00.

The subplot on the left for the pump considers only the frequency band from 31.6 to 35.4 Hz and we see 2 steps (two "ON" periods) in this 5-hour period that match CIR command setting change times. We see the pump is prevalent on the X-axis.

Similarly, for the fans' subplot on the right, we consider the frequency band from 51.6 to 54.3 Hz. The fans impact was primarily aligned with the XY-plane and the fans' RMS steps are much higher above the "OFF" baseline than for the pump's steps – compare the vertical, RMS axis on the 2 subplots.

GMT 2022-06-28/13:30, 5-Hour Interval RMS vs. Time

The interval RMS vs. time plot of Figure 14 on page 17 shows the first operations period from GMT 2022-06-28, 5 hours starting at 13:30.

The subplot on the left for the pump considers only the frequency band from 31.6 to 35.1 Hz and we see a step above baseline ("OFF") in this 5-hour period

that matches the CIR command setting change times. We see the pump is prevalent on the X-axis.

The fans' subplot on the right shows that we consider the frequency band from 58.4 to 59.9 Hz – the upper end of this band being uncomfortably close to 60 Hz, where the RMS signal would otherwise get swamped by other, stronger equipment vibrations at that frequency. Parseval gave us a way to avoid that misstep. The fans impact was primarily aligned with the XY-plane and the fans' RMS step was much higher above the "OFF" baseline than for the pump's step – compare the vertical, RMS axis on the 2 subplots.

Note that the fans' impact in this period was around 44% higher than on GMT 2022-04-14 in terms of total RMS.

GMT 2022-06-28/20:00, 5-Hour Interval RMS vs. Time

The interval RMS vs. time plot of Figure 15 on page 18 shows the second operations period from GMT 2022-06-28, 5 hours starting at 20:00.

The subplot on the left for the pump considers only the frequency band from 31.6 to 35.1 Hz and we see a step above baseline ("OFF") in this 5-hour period that matches the CIR command setting change times. We see the pump is prevalent on the X-axis.

The fans' subplot on the right shows that we consider the frequency band from 54.6 to 57.3 Hz. The fans impact was primarily aligned with the XY-plane and the fans' RMS step was much higher above the "OFF" baseline than for the pump's step – compare the vertical, RMS axis on the 2 subplots.

Note that the fans' impact in this period was just under 30% higher than on GMT 2022-04-14 in terms of total RMS.

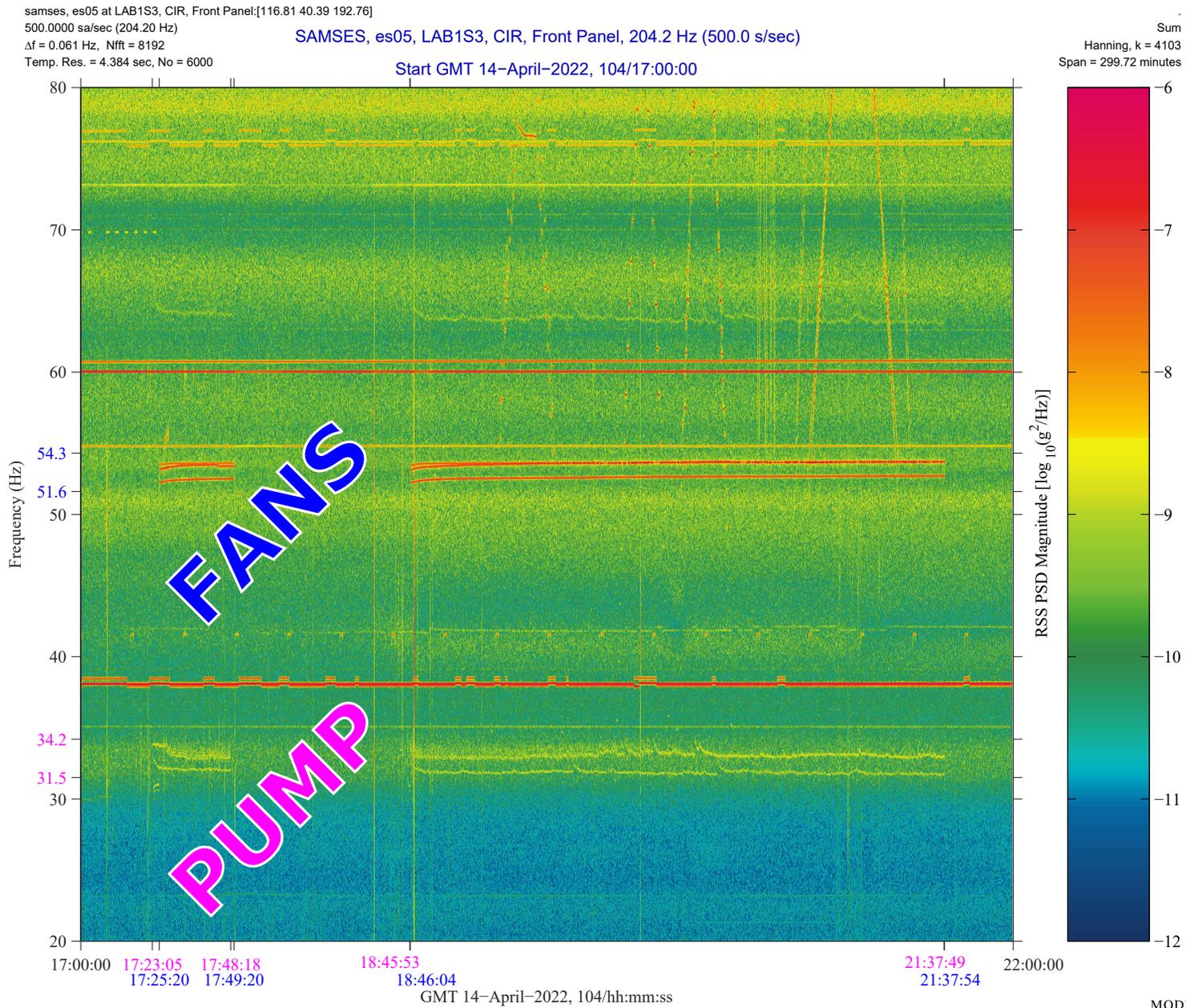
4. CONCLUSION

The SAMS measurement data from GMT 2022-04-14 and GMT 2022-06-28 have been analyzed, and the SAMS sensor (TSH ES-05) measurements from the CIR facility on those days **show good SAMS timing correlation relative to the CIR cmd.par setting change timestamps**. We were able to isolate and quantify the impact of each of the CIR facility equipments' operations on the vibratory environment in terms of RMS acceleration. Details in the figures throughout and summary in the tables at the end of this document.

5. OPEN ITEMS

Some potential follow-up objectives:

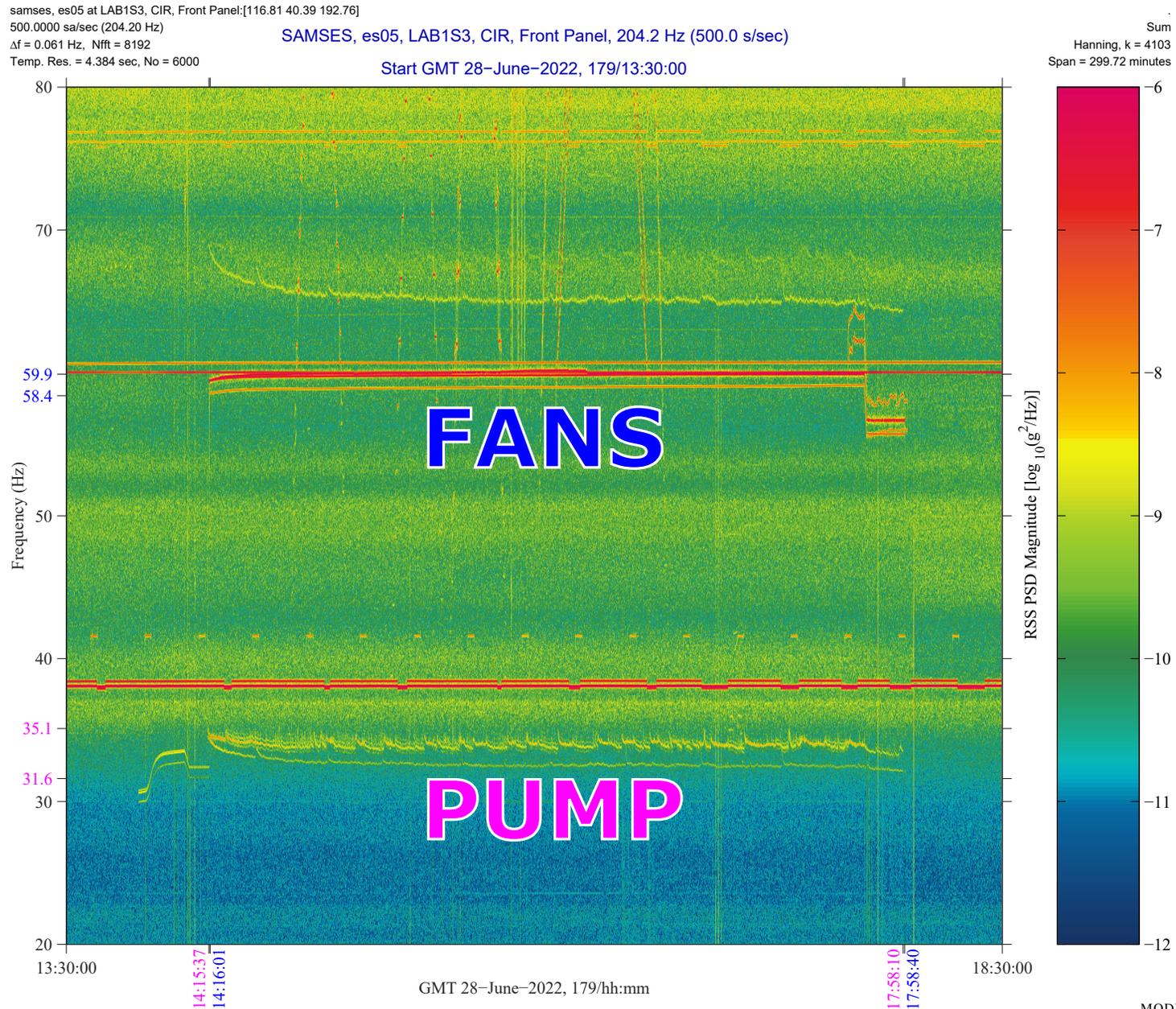
- 1) See Table 2 on page 20 for this question:
Why no obvious correlation with SAMS for the command shown in red?
- 2) Propose, develop, and deploy a near real-time display (perhaps interval RMS vs. time to augment spectrogram) to possibly help operators focus on or confirm CIR pump & fans operations?



VIBRATORY

MODIFIED JULY 22, 2022

Fig. 1: SAMS es05 (CIR) Sensor Color Spectrogram Below 200 Hz, 5 Hours Starting at GMT 2022-04-14/17:00.



VIBRATORY

MODIFIED JULY 22, 2022

Fig. 2: SAMS es05 (CIR) Sensor Color Spectrogram for CIR Fans & Pump, 5 Hours Starting at GMT 2022-06-28/13:30.

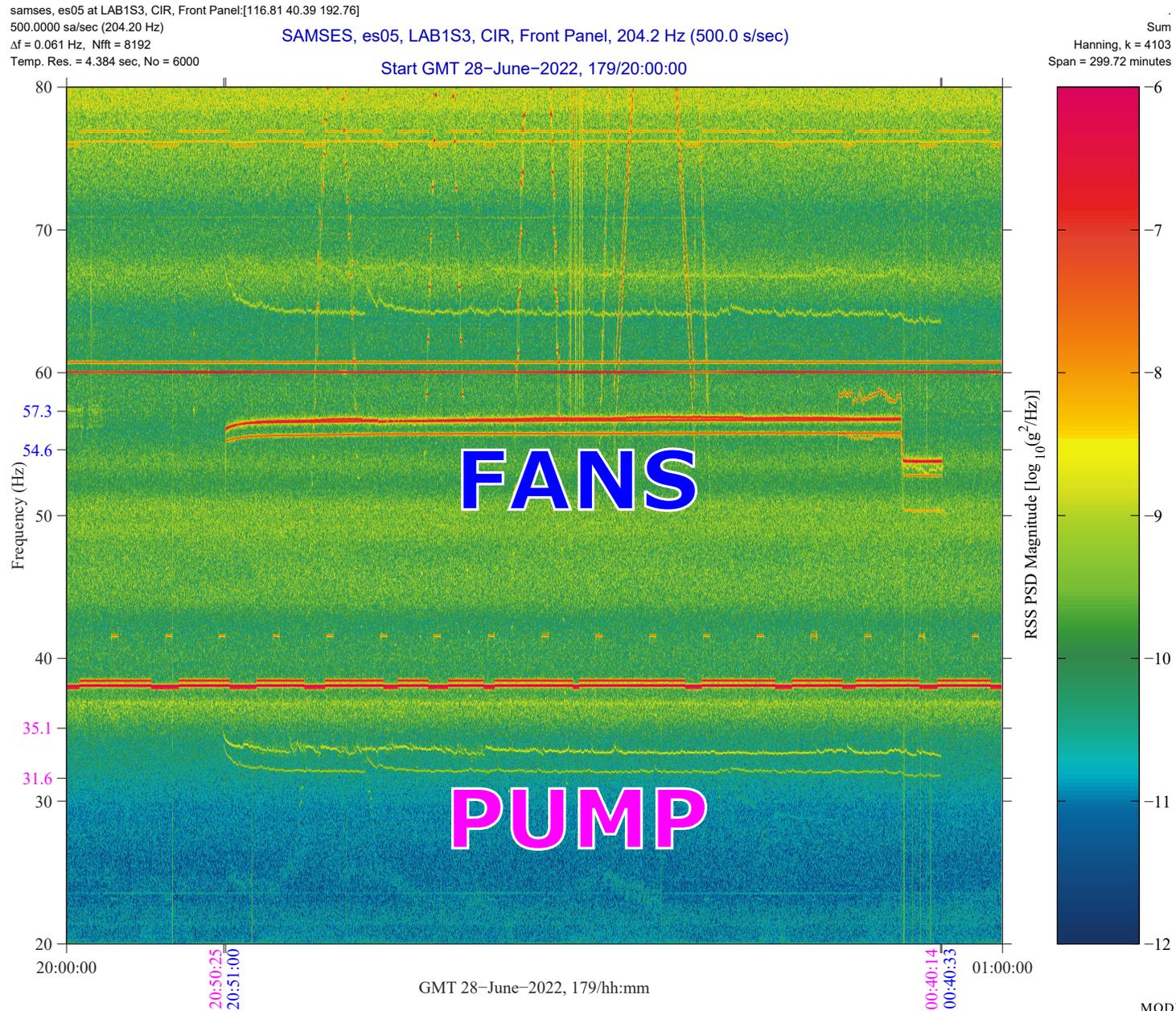


Fig. 3: SAMS es05 (CIR) Sensor Color Spectrogram for CIR Fans & Pump, 5 Hours Starting at GMT 2022-06-28/20:00.

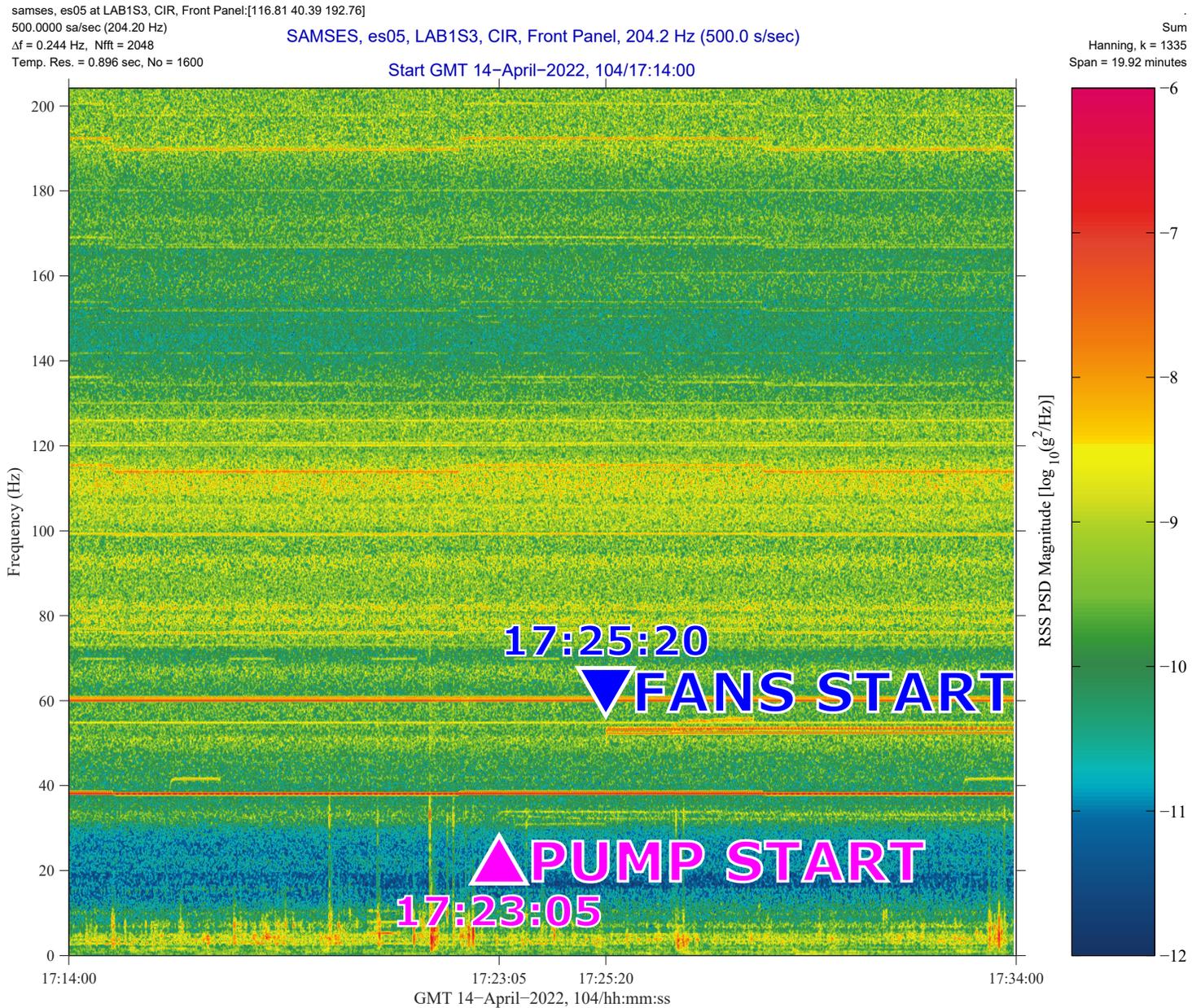


Fig. 4: SAMS es05 (CIR) Sensor Color Spectrogram Below 200 Hz Starting GMT 2022-04-14/17:14:00.

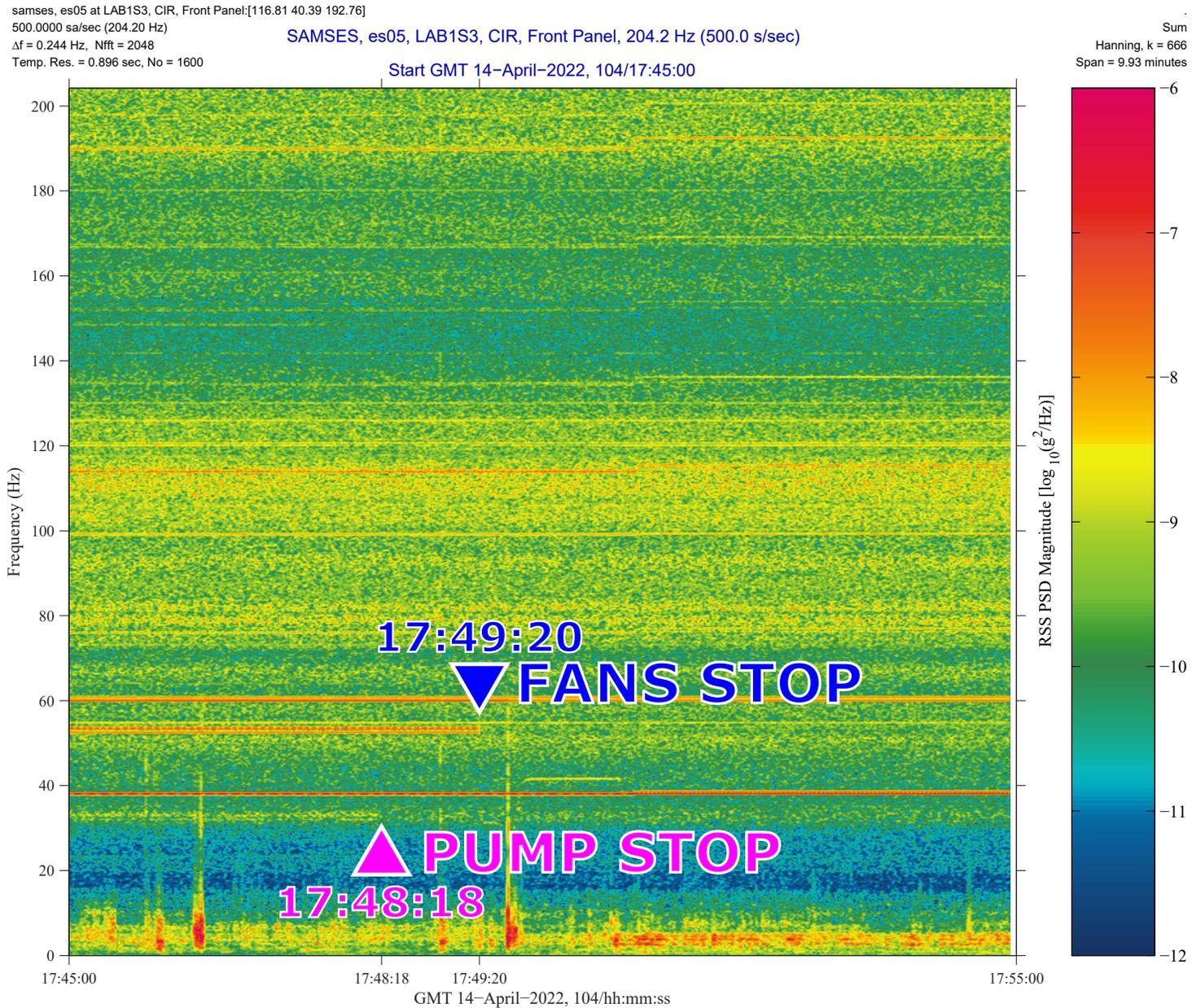


Fig. 5: SAMS es05 (CIR) Sensor Color Spectrogram Below 200 Hz Starting GMT 2022-04-14/17:45:00.

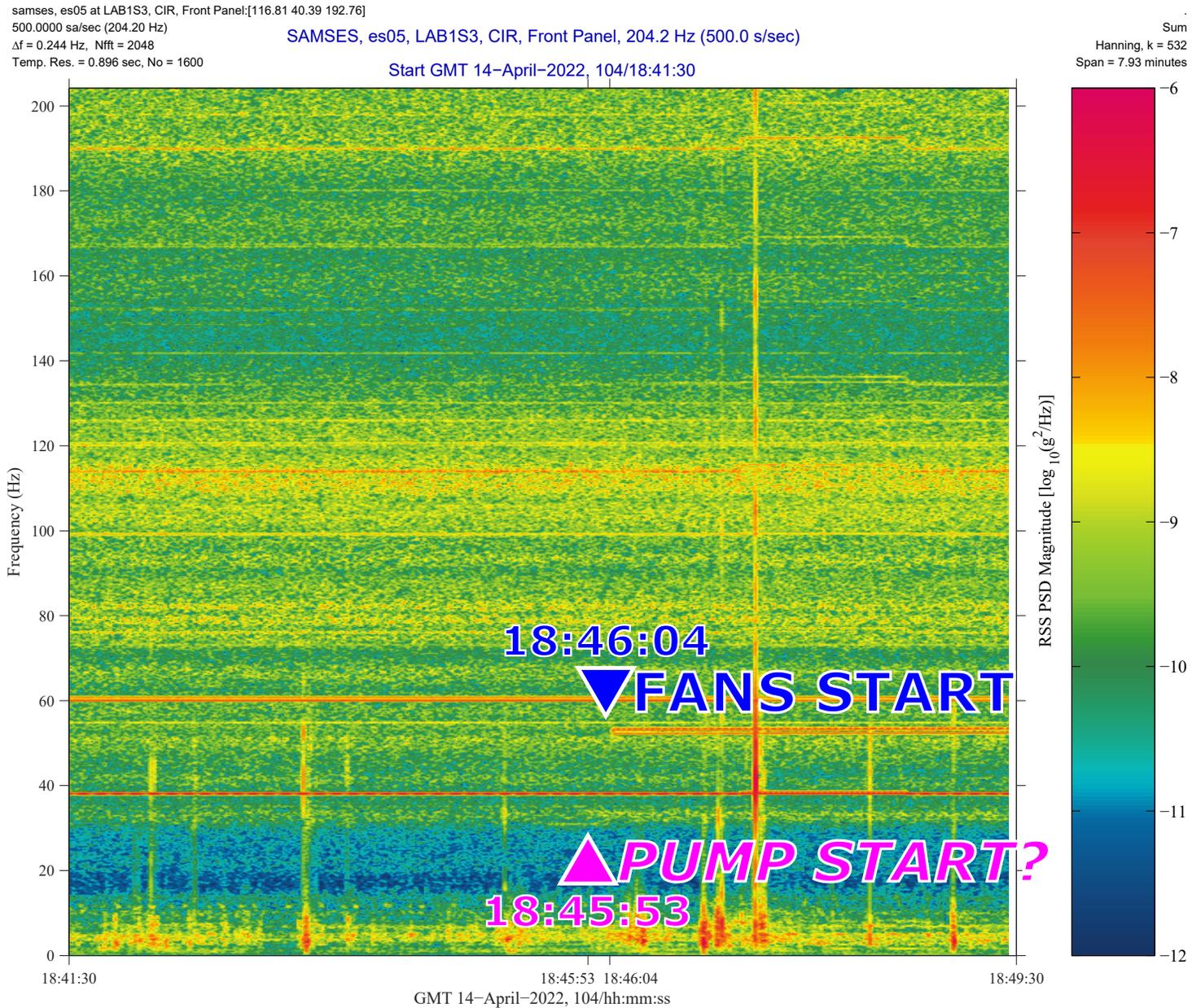


Fig. 6: SAMS es05 (CIR) Sensor Color Spectrogram Below 200 Hz Starting GMT 2022-04-14/18:41:30.

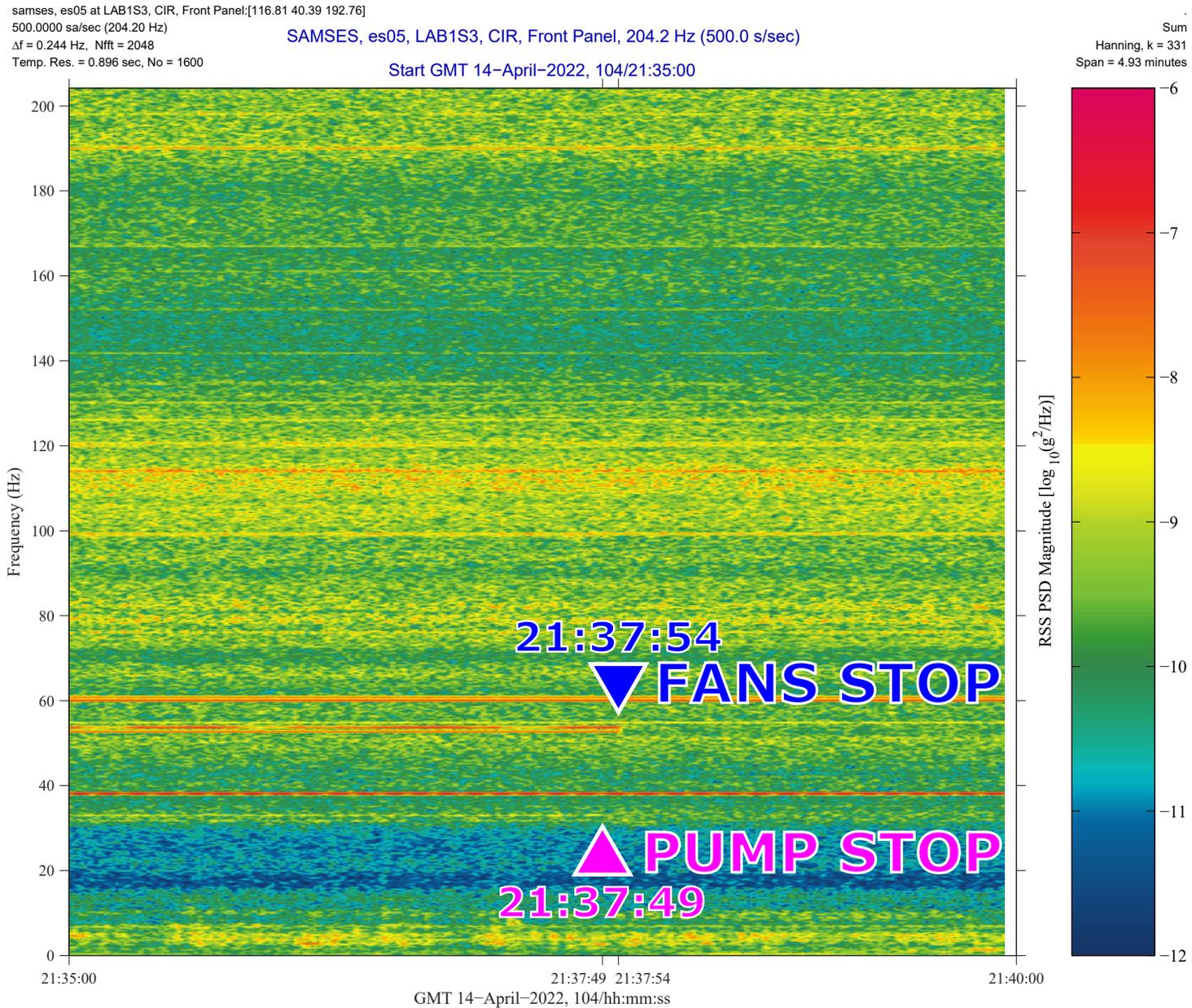
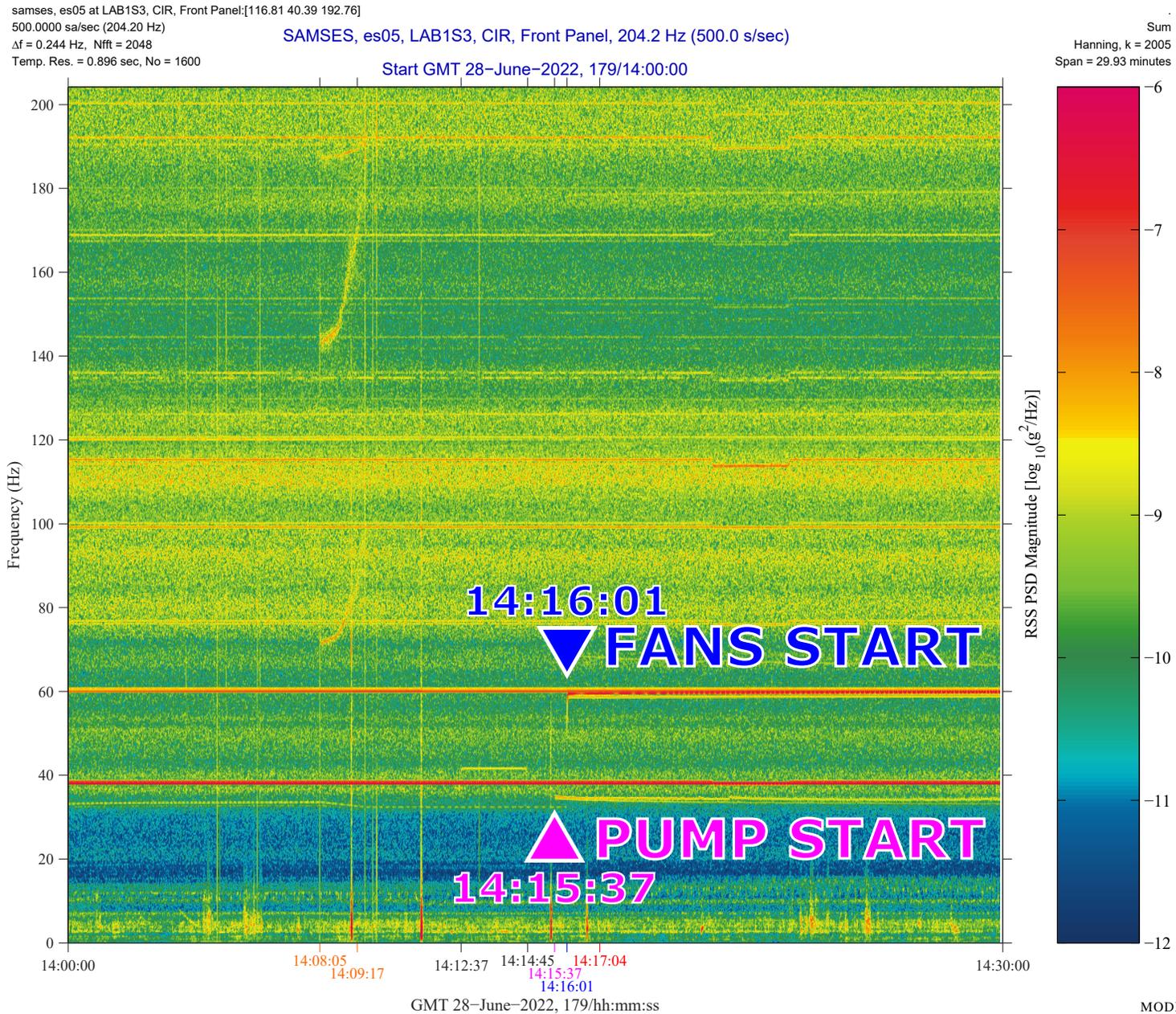


Fig. 7: SAMS es05 (CIR) Sensor Color Spectrogram Below 200 Hz Starting GMT 2022-04-14/21:35:00.



VIBRATORY

MODIFIED JULY 22, 2022

Fig. 8: SAMS es05 (CIR) Sensor Color Spectrogram Below 200 Hz Starting GMT 2022-06-28/14:00:00.

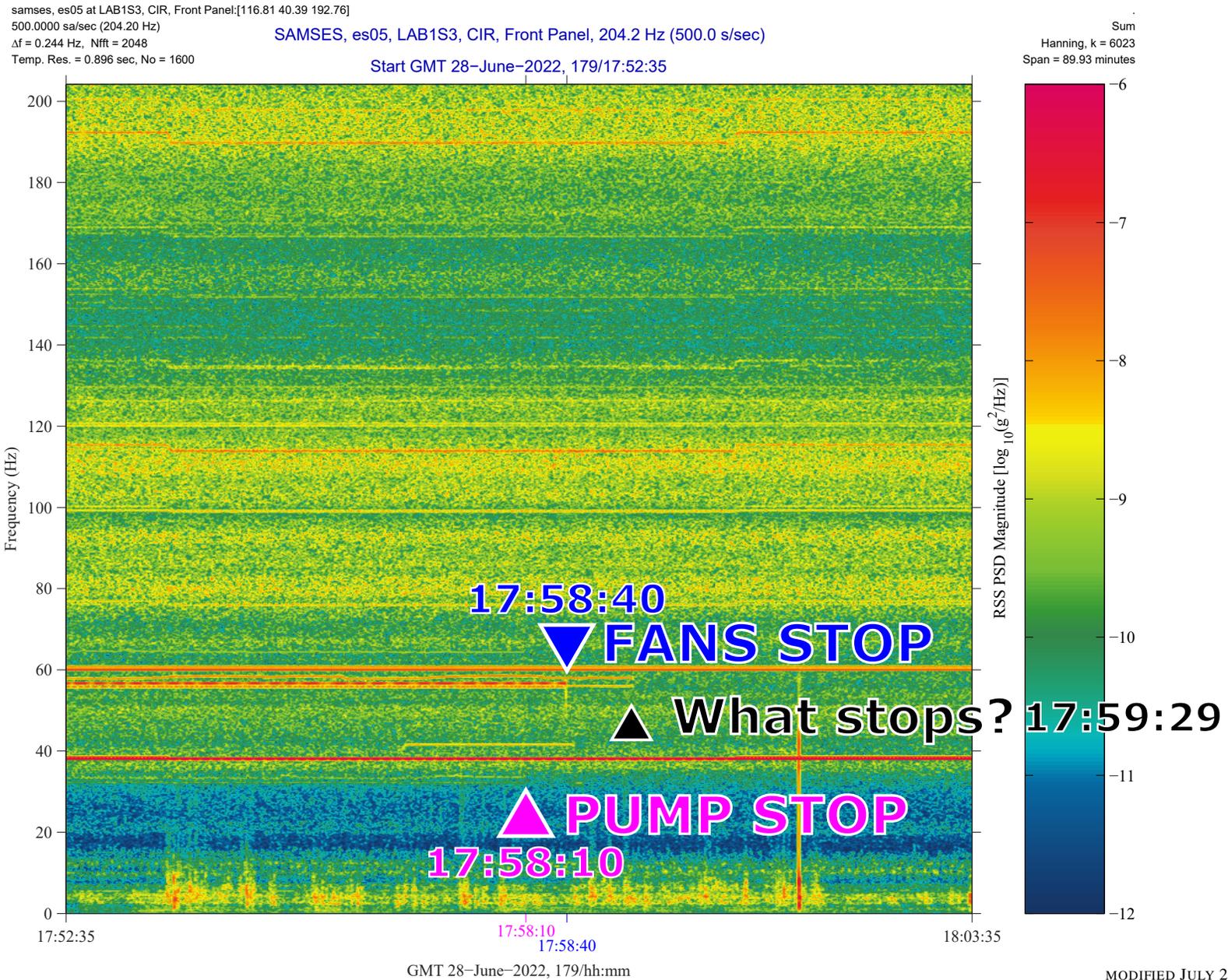


Fig. 9: SAMS es05 (CIR) Sensor Color Spectrogram Below 200 Hz Starting GMT 2022-06-28/17:52:35.

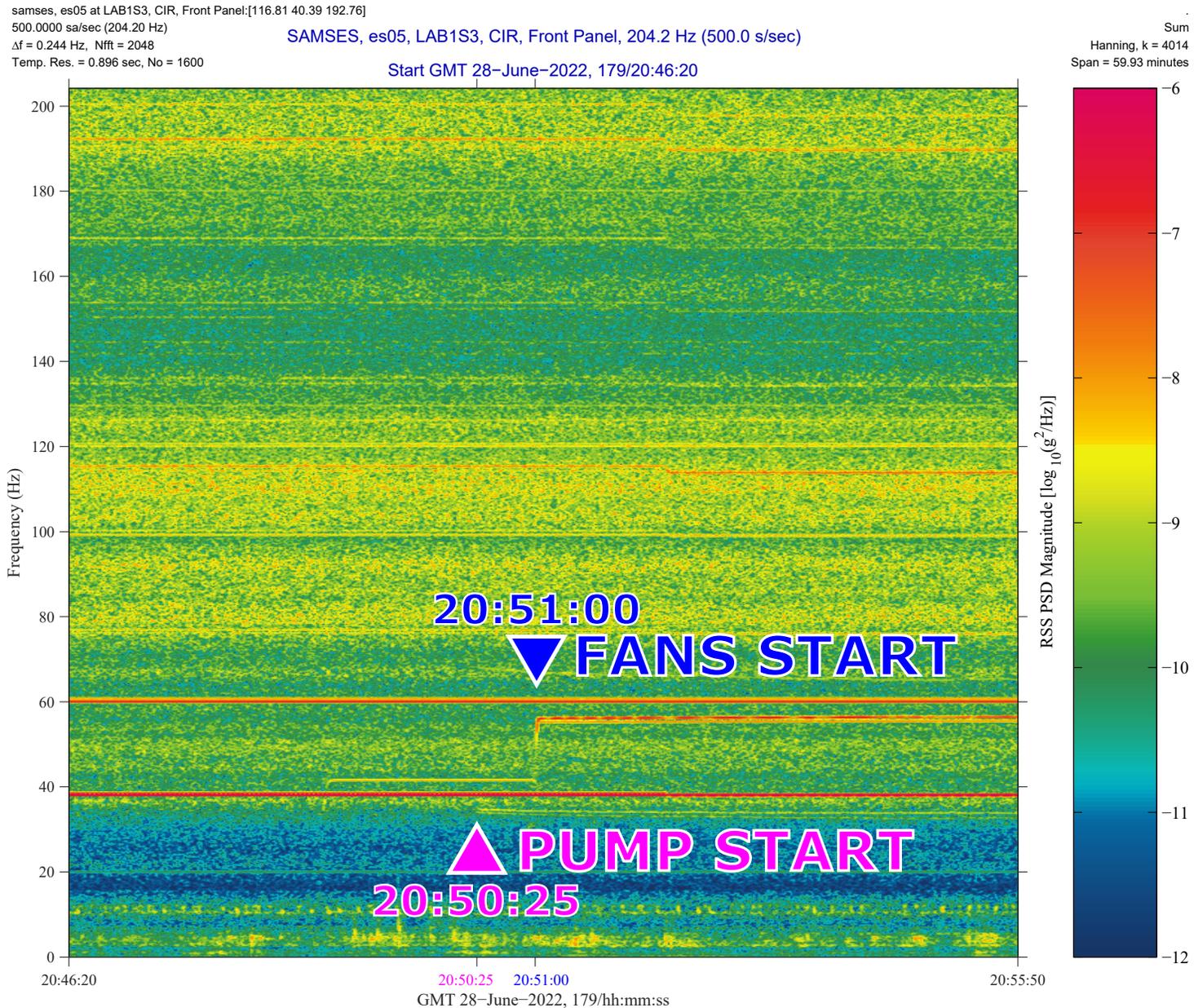


Fig. 10: SAMS es05 (CIR) Sensor Color Spectrogram Below 200 Hz Starting GMT 2022-06-28/20:46:20.

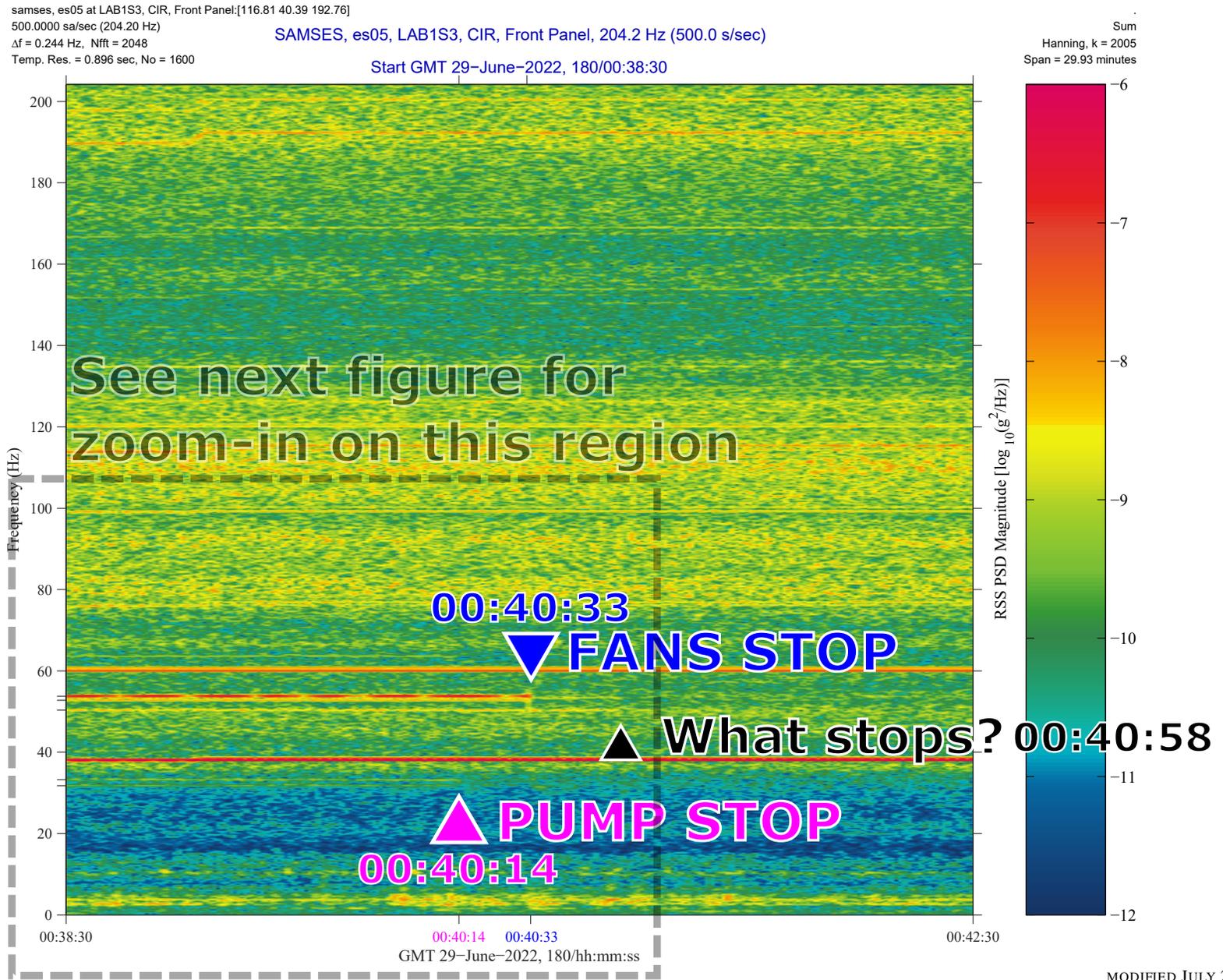
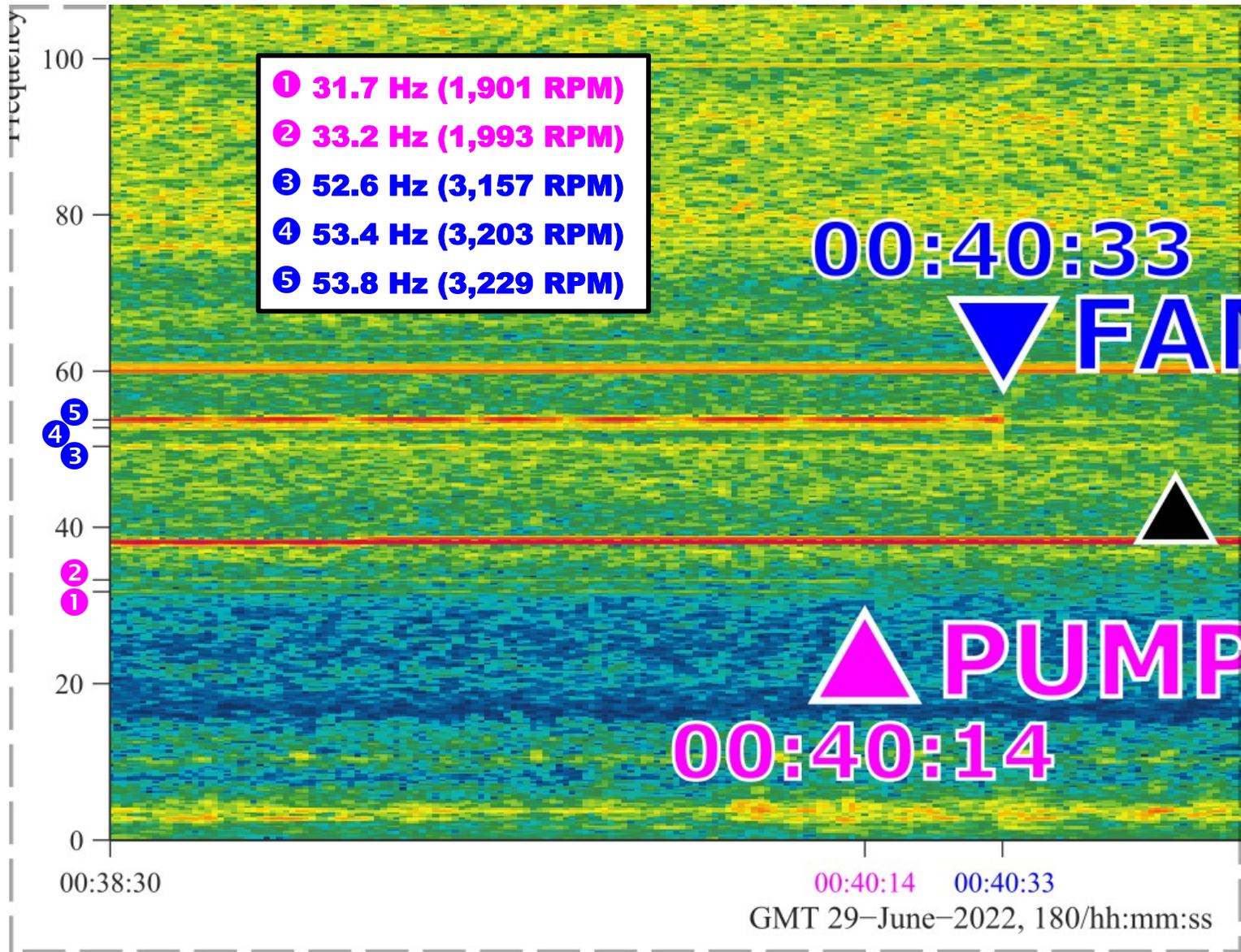


Fig. 11: SAMS es05 (CIR) Sensor Color Spectrogram Below 200 Hz Starting GMT 2022-06-29/00:38:30.



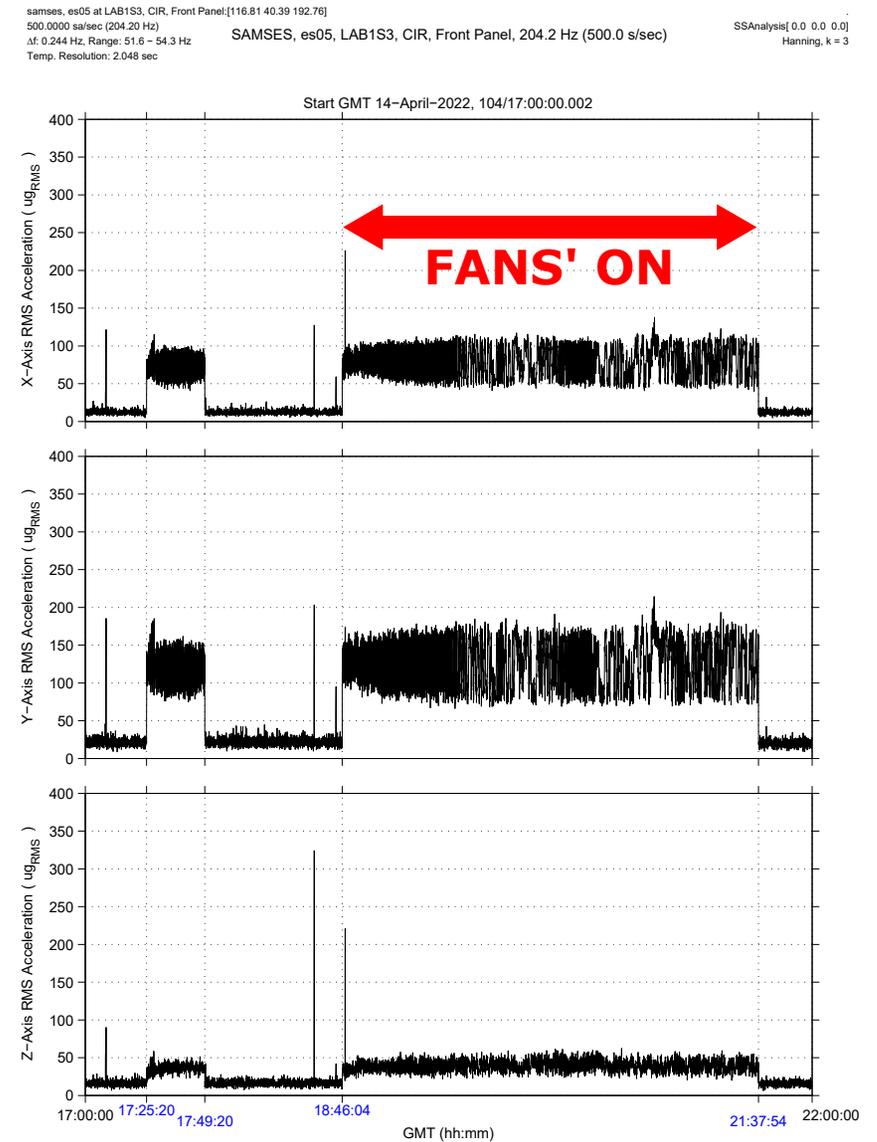
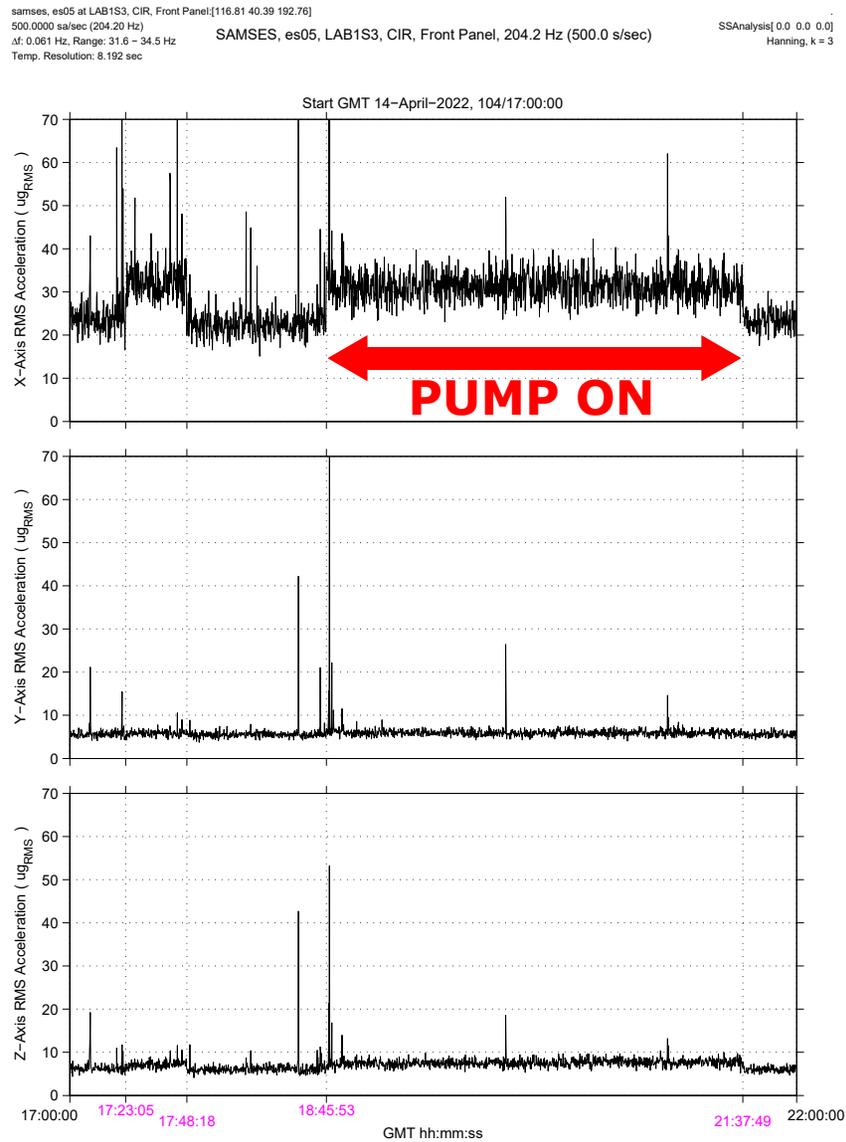


Fig. 13: SAMS es05 (CIR) Interval RMS for (left) Pump & (right) Fans' Frequency Bands, 5 Hours Start at GMT 2022-04-14/17:00.

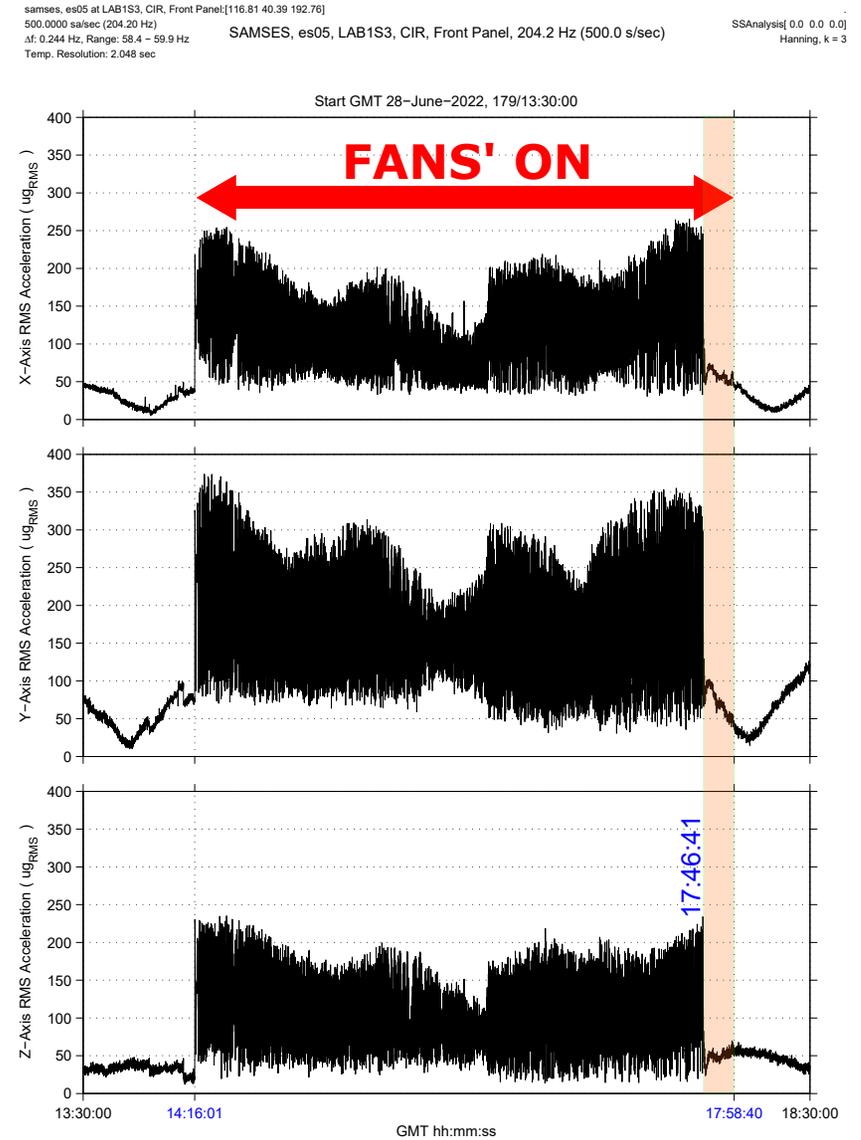
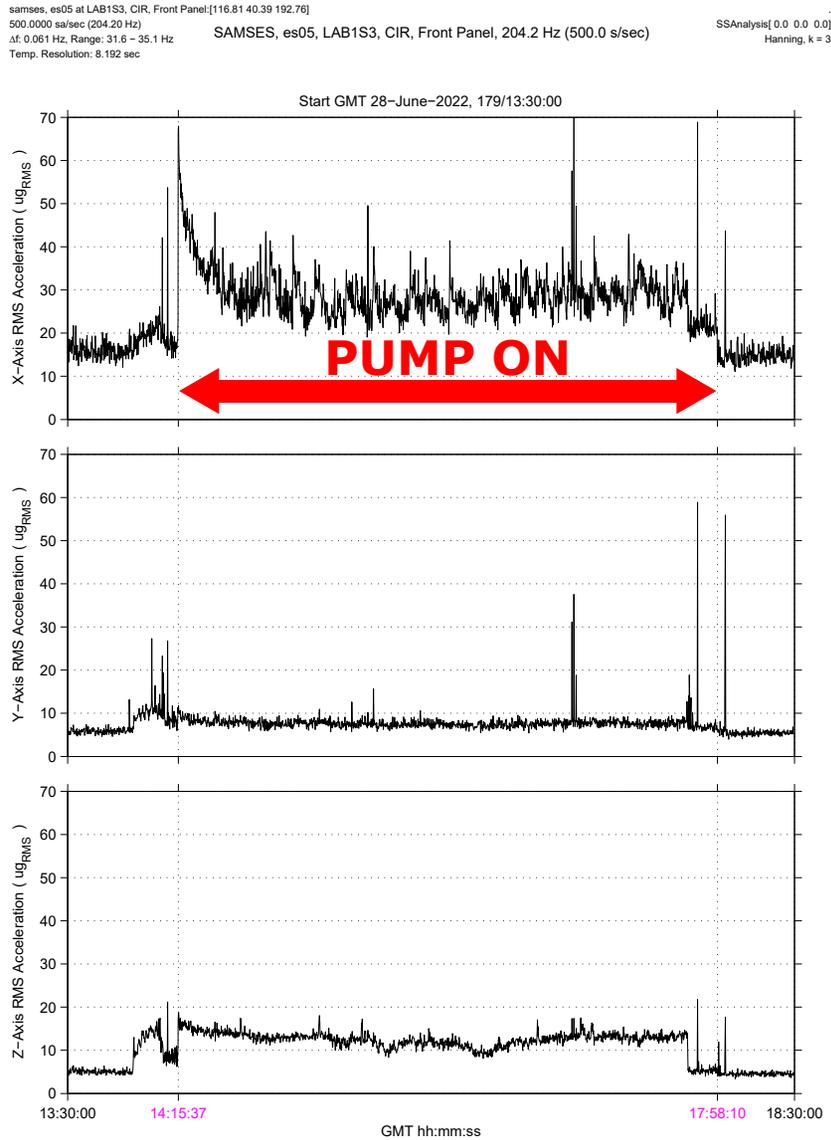


Fig. 14: SAMS es05 (CIR) Interval RMS for (left) Pump & (right) Fans' Frequency Bands, 5 Hours Start at GMT 2022-06-28/13:30.

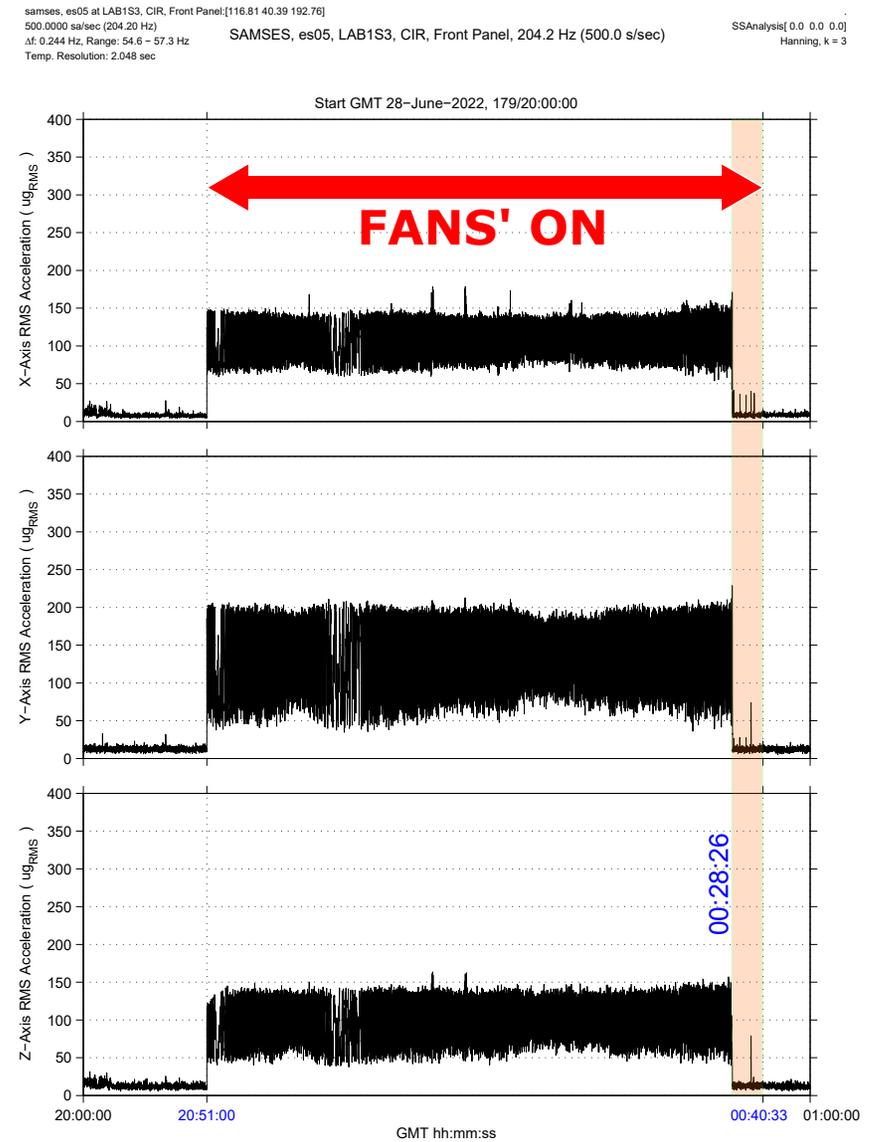
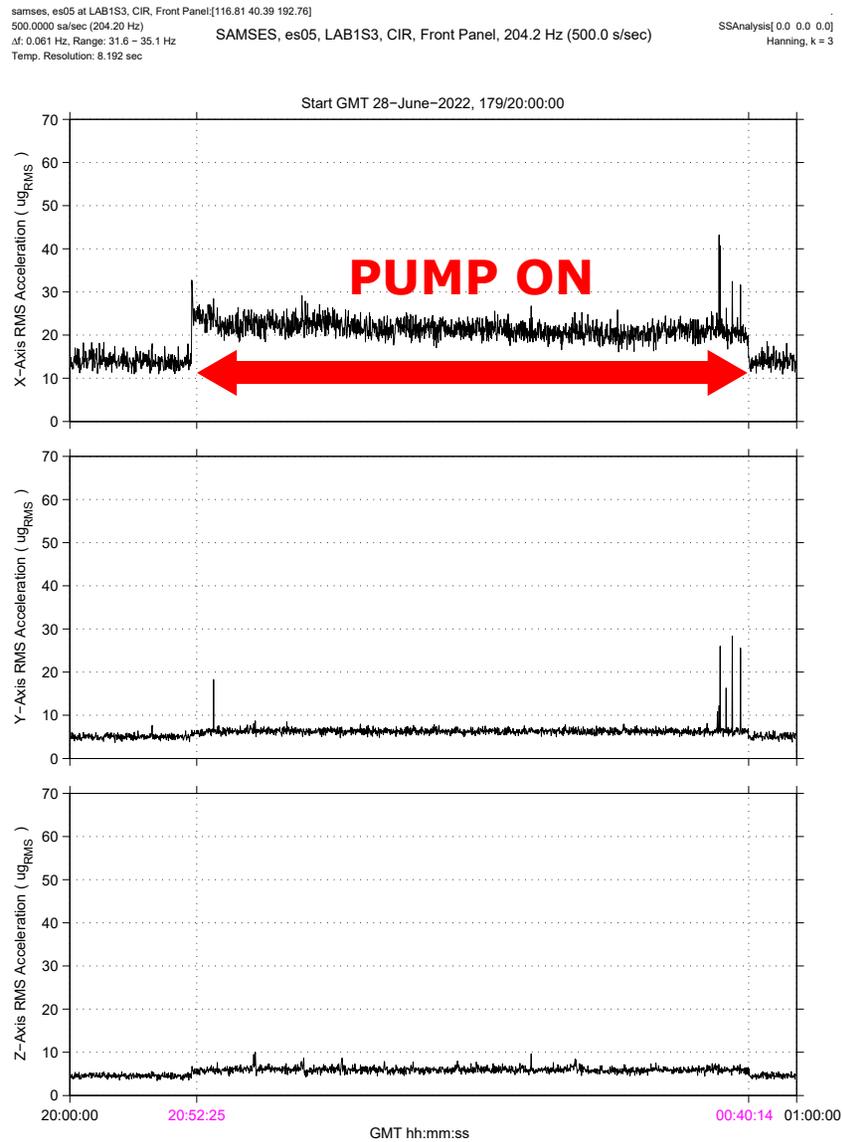


Fig. 15: SAMS es05 (CIR) Interval RMS for (left) Pump & (right) Fans' Frequency Bands, 5 Hours Start at GMT 2022-06-28/22:00.

Table 1. Compare Root-Mean-Square (RMS) Values (μg), CIR Pump and Fans' **ON** vs. **OFF**

GMT Span	Fans State	Band (Hz)	X-Axis	Y-Axis	Z-Axis	Total (RSS)
2022-04-14 17:48:18 to 18:45:53	PUMP OFF	31.6-34.5	22.5	5.5	6.1	24.0
2022-04-14 18:45:53 to 21:37:49	PUMP ON	31.6-34.5	31.3	5.9	7.5	32.7
2022-04-14 17:49:20 to 18:46:04	FANS OFF	51.6-54.3	11.9	21.3	16.2	29.3
2022-04-14 18:46:04 to 21:37:54	FANS ON	51.6-54.3	81.0	129.5	38.9	157.6
2022-06-28 17:58:10 to 18:30:00	PUMP OFF	31.6-35.1	14.5	5.4	4.6	16.1
2022-06-28 14:15:37 to 17:58:10	PUMP ON	31.6-35.1	28.0	7.6	12.6	31.6
2022-06-28 17:58:40 to 18:30:00	FANS OFF	58.4-59.9	24.4	60.6	48.8	81.5
2022-06-28 14:16:01 to 17:58:40	FANS ON	58.4-59.9	112.2	169.0	102.5	227.3
2022-06-28 20:00:00 to 20:52:25	PUMP OFF	31.6-35.1	13.9	5.1	4.6	15.5
2022-06-28 20:52:25 to 00:40:14	PUMP ON	31.6-35.1	21.4	6.3	5.9	23.1
2022-06-28 20:00:00 to 20:51:00	FANS OFF	54.6-57.3	8.1	12.2	12.4	19.2
2022-06-28 20:51:00 to 00:40:33	FANS ON	54.6-57.3	109.4	139.5	99.5	203.3

NOTE: In Adobe, when you use hyperlinks in table below, you can use Ctrl+End to easily jump back to this page.

Table 2. CIR Pump & Fans' Command Settings & SAMS Notes & (blue) Hyperlinks (SPG = spectrogram, RVT = interval RMS)

GMT	Event	SAMS Notes & Hyperlinks
4/14/22 17:23:05	cmd 0xC208, set: 3	17:23:05 pump starts, mainly X-axis SPG , RVT
4/14/22 17:25:20	cmd 0xC209, set: 8	17:25:20 fans start, XY-planar vibes SPG , RVT
4/14/22 17:48:18	cmd 0xC208, set: 0	17:48:18 pump stops SPG , RVT
4/14/22 17:49:20	cmd 0xC209, set: 0	17:49:20 fans stop SPG , RVT
4/14/22 18:45:53	cmd 0xC208, set: 3	18:45:53 pump starts (indistinct in spectrogram) SPG , RVT
4/14/22 18:46:04	cmd 0xC209, set: 8	18:46:04 fans start SPG , RVT
4/14/22 21:37:49	cmd 0xC208, set: 0	21:37:49 pump stops SPG , RVT
4/14/22 21:37:54	cmd 0xC209, set: 0	21:37:54 fans stop SPG , RVT
6/28/22 14:15:39	cmd 0xC208 set 3	14:15:37 pump starts, interval RMS has poor temporal resolution SPG , RVT
6/28/22 14:16:02	cmd 0xC209 set 8	14:16:01 fans start, interval RMS has poor temporal resolution SPG , RVT
6/28/22 14:17:04	cmd 0xC209 set 8	no distinctive vibratory changes SPG
6/28/22 17:58:10	cmd 0xC208, set: 0	17:58:10 pump stops SPG , RVT
6/28/22 17:58:40	cmd 0xC209, set: 0	17:58:40 fans stop SPG , RVT
6/28/22 20:50:25	cmd 0xC208, set: 3	20:50:25 pump starts SPG , RVT
6/28/22 20:51:00	cmd 0xC209, set: 8	20:51:00 fans start SPG , RVT
6/29/22 00:40:14	cmd 0xC208, set: 0	00:40:14 pump stops SPG , RVT
6/29/22 00:40:32	cmd 0xC209, set: 0	00:40:32 fans stop SPG , RVT

The commands in the CIR cmd.par have two time stamps:

- 1) *Timestamp Column* = offset by about +18s from Command Time Column
- 2) *Command Time Column*

and we show the Timestamp Column for CIR command times in all of the discussion here.